ENERGY METABOLISM IN OBESE PATIENTS*

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The statements of obese patients that they do not lose weight even though they eat scarcely anything might have been discounted. But when Von Noorden and other early students of this condition reported that some obese persons under their observation lost little or no weight while they were receiving low calory diets, it was but natural to infer that these patients were suffering from some metabolic aberration. There followed a long and arduous search for an abnormality in the energy exchange that would explain this peculiar conduct.

Basal Metabolism: It was soon reported that obese persons produce less heat per kilogram of body weight in the resting postabsorptive state than do normal controls. Had the comparison been made on the basis of height, it would have been found that the heat production of obese persons was greater than normal. But Rubner, Lusk and others had demonstrated that the basal heat production of all mammals is proportional to the area of the body surface and that no such relation exists when either weight or height alone is used as a basis of comparison.

Subsequently E. F. Du Bois[1] and his brother devised a method for calculating the area of the body surface that is suitable for clinical use and his technique has been universally accepted and employed. A few simple calculations show that with height stationary, doubling of body weight increases the area of the body surface about 40 per cent. Accordingly, in the case where basal heat production per square meter does not change as weight is gained, the heat production per kilogram will have decreased by about 40 per cent of its original value when body weight has doubled. If the obesity has developed in an adult, height will not have changed, but the basal heat production will have increased at nearly one-half the rate of the weight gain. Hence per unit of height the heat is abnormally great in obese persons. This shows the essential

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TABLE I

TOTAL BASAL HEAT PRODUCTION OF FIVE OBESE WOMEN COMPARED WITH IDEAL VALUES

	Weight lb.	*Surface Area, sq. M.*	*Calories/Sq. M./Hr.*	*Total Calories/Hr.*
Ideal	129	1.59	36.5	58
Observed	238	2.06	35.5	73

fallacy of referring calories to weight as was done by the early workers in this field.

Subsequent students have without exception compared the heat produced to the surface area when they wanted to deal with metabolic rates.

Boothby and Sandiford[2] using modern techniques measured the heat production in 94 obese patients and found that in 81 per cent of them the rates were within the normal band. In three instances, the rates fell between minus 16 and minus 20 per cent and one patient produced heat at a rate more than 16 per cent above normal.

Strouse, Wang, and Dye[3] compared the rates of normal persons with those who were underweight and overweight. They found no significant differences.

Among 180 cases of extreme obesity Grafe[4] found only three in which there was a definite decrease in basal rate.

Since occasional persons in whom no detectable disease exists are found to have basal rates as low as minus 15 to minus 25 per cent, it is evident that obesity is not caused by a lessened expenditure of energy in the basal state.

In fact, the total heat production of obese persons is greater than it is in corresponding normal persons, because the surface area is abnormally large in the former group. Instructive data are contained in Table I, taken from the paper by Strang and Evans[5] who compared the average values obtained from five obese women with a hypothetical normal control. It is seen that even though the heat production per square meter of body surface in the obese group is well within the normal range, nevertheless the total heat production per hour is markedly increased due to the augmented surface area.

Specific Dynamic Effect: If the heat production of a person who has been without food for eighteen hours and who has been reclining quietly, is recorded and he is then fed, he will shortly produce more heat than he did in the fasting state. The failure to respond in this way, would result in gain of weight, provided the person continued to ingest precisely the same number of calories and provided there was no change in activity.

Several authors attempted to attribute obesity to lessened caloric response to food. However, both Dürr[6] and Lauter[7] emphasized the great variability in the specific dynamic response exhibited by normal persons and cast doubts upon the interpretations of earlier investigations.

Strang and McClugage,[8] fully aware of the many hazards surrounding the measurement of the specific dynamic response to food, conducted their studies so painstakingly that they inspire great confidence. They recorded the total increase in heat production for the eight hours following the ingestion of a test meal. The average increase over the basal value in eight obese subjects was 58 calories, whereas the response of five normal persons was 51 calories. Evidently obesity is not attributable to lessened dynamic response to food.

Luxuskonsumption: Grafe[9] conceived the idea that the heat production is influenced by the quantity of food eaten. It was postulated that the twenty-four hourly expenditure of energy increases as intake of food increases after full allowance has been made for the calories of the basal metabolism, the specific dynamic response and activity. The opposite effect would be caused by underfeeding. Obesity would result when this mechanism failed to respond to overeating. Unfortunately the experiments that Grafe performed to substantiate this hypothesis were poorly conceived and quite unconvincing. Our own studies[10] give no support to Grafe's conception.

Total Metabolism: It has been repeatedly observed that obese persons who are certainly receiving only minimal quantities of food may fail to lose weight. Such paradoxical conduct could arise from some obscure metabolic abnormality that permits unusual conservation in the expenditure of energy. In that case the total heat production would be definitely less than the predicted value. Whether a disturbance of this sort does exist can be decided by recording the twenty-four hourly heat production. This may be done by indirect calorimetry with the subject enclosed in a respiration chamber. But the data will not be entirely adequate to answer the question, because the subject is neces-

TABLE II

ENERGY METABOLISM IN OBESE PATIENTS

INSENSIBLE LOSS OF WEIGHT

		Grams
Initial body weight		70,000
Food + Water	2,800	
Urine + Feces	1,600	
Difference	1,200	
Final body weight		70,000
Insensible loss of weight	1,200	

REMOVAL OF HEAT BY EVAPORATION OF WATER

I. L. = Water Vapor (I. W.) + $CO_2 - O_2$
I. W. = I. L. — ($CO_2 - O_2$)
I. W. × 0.58 = Heat removed by evaporation

When I. W. = 0.93 I.L., then I.L. × 0.93 × 0.58 = Cal. lost in outgoing water vapor.

sarily quite inactive and the periods are limited to twenty-four or possibly forty-eight consecutive hours. Both of these limitations can be avoided by using the insensible loss of weight as a basis for the calculations. This method rests on the following considerations: Water is evaporated continuously from the skin and lungs. This is a means of removing heat since it requires 0.58 calories to convert one gram of water from the liquid to the gaseous state at usual body temperatures. This evaporation of water causes a continuous loss of weight which is slightly increased by the respiratory exchange of gases since the weight of the outgoing CO_2 exceeds that of the ingoing O_2. This relationship is expressed by the following equation: I.L. = I.W. + $CO_2 - O_2$ where I.L. is insensible loss of weight and I.W. is the weight of the evaporated water. The loss of weight that occurs when the individual takes nothing by mouth and excretes no urine or feces, is the insensible loss of weight. When it is desired to measure this loss of weight for twenty-four hourly periods, it is merely necessary to add the weight of the ingesta to the initial body weight and the weight of the excreta to the final body weight and to subtract the second sum from the first one. The difference is the insensible loss of weight. These relationships are shown in Table II.

Evaporation of water takes place even when the sweat glands are completely inactive. This is the condition when violent exercise is avoided and when the air is cool enough to permit complete comfort. Under these circumstances the weight of the water vapor varies from about 700 to 1500 grams per twenty-four hours in adults, depending upon size and activity. This corresponds to the removal of 406 calories ($700 \times .58$) to 870 calories ($1500 \times .58$) by this route.

Earlier students[11] had shown that there is a quantitative relationship between the hourly insensible loss and the basal metabolism. In order to determine whether the heat removed by vaporization of water is proportional to heat production for twenty-four hourly intervals on the part of persons who are leading their usual lives, the following procedures were carried out.[12] A number of individuals were placed on diets which were considered to be close to maintenance and an accurate body weight was obtained each morning at the same time under the same conditions. If there was progressive gain or loss of weight, the calories of the diet were adjusted appropriately until constancy of weight was achieved. It could then be assumed that the subjects were in energy balance and that the total loss of heat was equal to the calories of the diet. Since the composition of the diet was known, it was possible to calculate the weights of the CO_2 produced and of the O_2 absorbed. Subtraction of the difference between these two weights from the twenty-four hourly insensible loss of weight, gave the weight of the water vapor. This value was then converted to its heat equivalent by multiplying by 0.58, which is the amount of heat in calories required to change one gram of water from the liquid to the gaseous phase. From these data, the per cent of the total heat, removed by evaporation of water, was calculated. Table III shows the data obtained from twelve individuals. It will be seen that the total variation in heat removed by evaporation of water was only from 23.8 per cent to 25.2 per cent, even though the heat production varied from 2,200 to 3,600 calories per 24 hours. These studies indicate that human beings exhibit a striking tendency to rid themselves of a fixed per cent of the heat produced in twenty-four hours by vaporization of water, provided only that they are comfortable in regard to environment. Therefore total heat production can be calculated from the weight of the water vaporized. But this latter value can not be obtained directly from persons who are moving about freely. However, a few calculations show that the water vapor makes up from 93 per cent to 98 per cent of the insensible loss of weight depending upon whether relatively much or little carbohy-

TABLE III

PERCENTAGE OF TOTAL HEAT LOST BY EVAPORATION OF WATER

Age yr.	*Heat lost by Evaporation of water, Percent*	*Comment*
56	23.8	Diabetic Patient
30	24.2	Diabetic Patient
28	24.2	Chemist
24	24.4	Chemist
25	24.1	Medical Student
23	24.7	Graduate Student
24	25.2	Graduate Student
24	24.2	Student
18	24.3	Patient in bed
15	24.8	Patient in bed
18	24.8	Patient in bed
47	24.7	Patient in bed

TABLE IV

ENERGY METABOLISM IN OBESE PATIENTS

Heat Production = Insensible Loss $\times$ 0.93 $\times$ 0.58 $\times$ 4.08
0.93 $\times$ 0.58 $\times$ 4.08 = 2.20

Example of Calculation of Heat Production for 24 Hours from Insensible Loss of Weight

	Gms.		*Gms.*
First Body Wt.	158,450	Second Body Wt.	158,700
Food and Drink	2,920	Urine	1,200
		Stool	250
	161,370		160,150

Insensible Loss — 161,370 — 160,150 = 1,220. 1,220 $\times$ 2.20 = 2,684 Calories

drate is being metabolized. Accordingly the insensible loss of weight, a value easily obtained, can be used conveniently as the basis for calculating the heat production.

The following equation is applicable when maintenance diets of the usual mixed variety are fed: Heat = I.L. $\times$ 0.93 $\times$ 0.58 . 4.08. Simplified: Heat = I.L. $\times$ 2.2. Where 0.93 is the per cent of the insensible loss of weight that consists of water vapor; 0.58 is the factor for converting weight of water evaporated to heat (calories); 4.08 is the factor for deriving total heat from heat lost by vaporization. An example of the calculation is seen in Table IV.

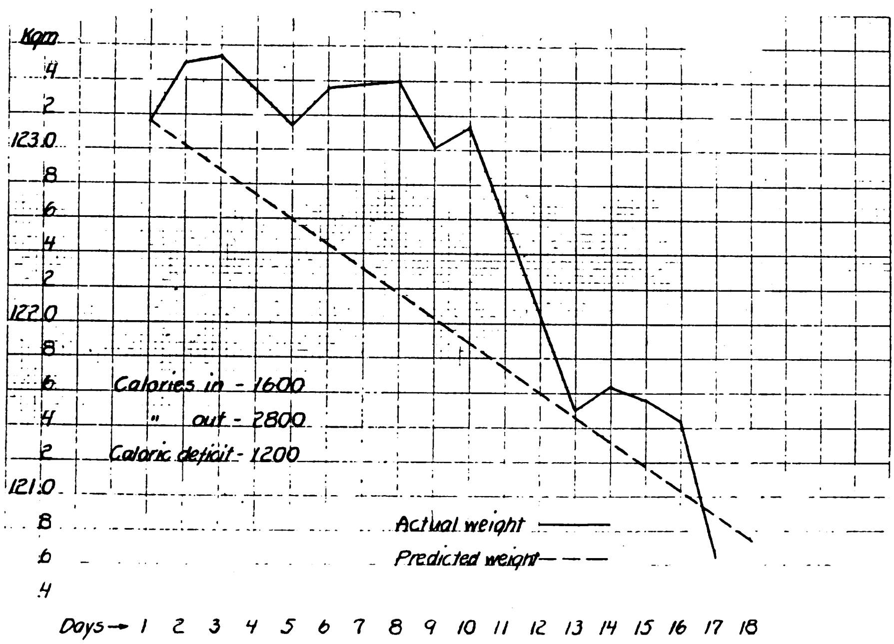


Fig. 1.

About 150 grams of body tissue were consumed daily to yield the 1200 calories not contained in the diet. Nevertheless, the body weight had declined only 100 grams by the tenth day. During the next three days, the patient lost about 1600 grams even though no change in diet had been made. The weight had now fallen to the value obtained by subtracting the weight of the body tissue destroyed during the thirteen days from the initial body weight.

In undernutrition, the same calculation is used except that the water vapor is now assumed to occupy 98 per cent of the insensible loss of weight since most of the heat is derived from the oxidation of fat. This difference is satisfied by multiplying I.L. by 2.3 instead of 2.2.

By means of this technique, the heat production of a number of obese persons was recorded consecutively in twenty-four hourly periods for several weeks and sometimes even for months. Included in the series were the various types of obesity described in the literature, namely: (1) a physically normal person except for the excessive weight, who frankly admitted years of gluttony, (2) a feeble-minded girl with a low basal rate, (3) a girl with disease of the pituitary body and a basal metabolic rate 30 per cent below normal, (4) a middle-aged woman whose weight had reached 295 pounds after an operation on the pitui-

Table V—ENERGY METABOLISM IN OBESE PATIENTS

FACTORS IN WATER BALANCE

Sources of Water	*Excretory Water*
1. Water of food	1. Water of urine
2. Water drunk	2. Water of stool
3. Water of oxidation	3 Insensible water
4. Preformed water	

tary body eight years earlier, (5) a young woman suffering from so-called Dercum's disease, (6) a middle aged woman five feet two inches tall, whose weight had reached 420 pounds—menopausal obesity. In no instance was the heat production less than the predicted value for comparable persons of normal weight. In fact, just the opposite was true. The obese patients invariably produced more heat per twenty-four hours than similar normal persons leading comparable lives.

Nevertheless, we, as had our predecessors, encountered obese patients who while receiving low calory diets, lost no weight for a number of days. An example of this phenomenon is found in Figure 1. The patient, a young woman, weighed 275 when she entered the hospital. Her basal metabolic rate per square meter of body surface was normal; but the total basal heat production was 2100 calories per twenty-four hours, about 600 calories greater than the predicted value for a comparable woman of normal weight. She remained in bed throughout the study. However, in spite of the inactivity, her twenty-four hourly heat production averaged 2800 calories. This was at least 800 calories greater than normal. Her diet contained 1600 calories daily. This produced a deficit of 1200 calories per day and calculation from the metabolic data indicated that she was oxidizing about 150 grams of body tissue daily as a source of these 1200 calories. Nevertheless, she lost only 100 grams during the first ten days. For the next three days, without any change in treatment, she lost about 1600 grams, and this was sufficient to bring her weight down to the predicted amount for that day. This very rapid loss of weight was far in excess of what could be explained by destruction of body tissue and compensated entirely for the stationary weight during the first ten days. Such a biphasic response suggested that the patient's body water was increasing progressively during the first phase in amounts whose weight roughly equalled that of the body

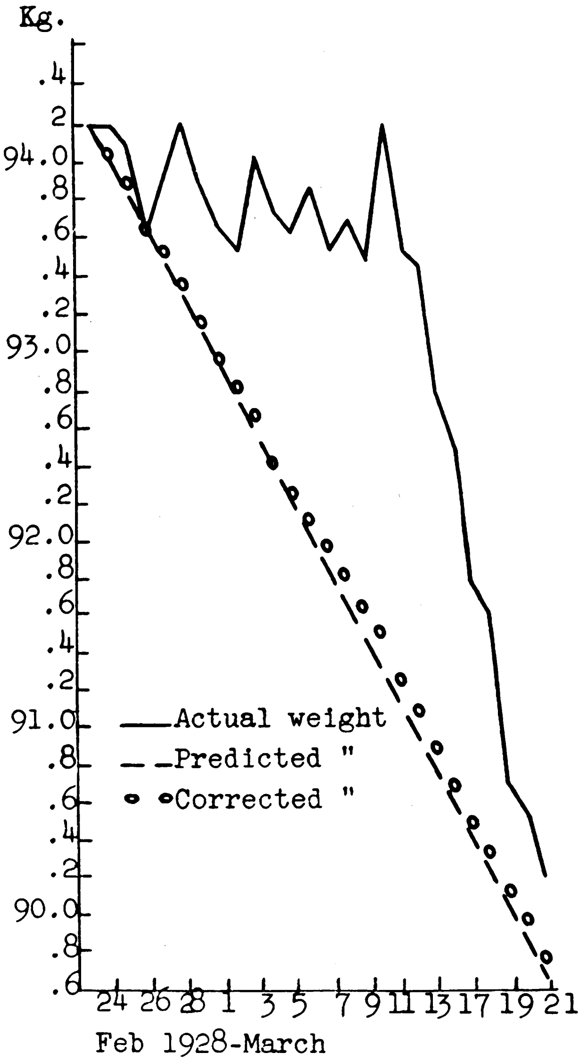


Fig. 2.

In spite of a daily deficit of 1225 calories, the patient weighed as much on the sixteenth day as she did on the first day. This was brought about by a progressive increase in body water. Subtraction of the weight of the excessive water from the actual body weight each day, gave values that agreed with the values obtained, by subtraction of the weights of the tissue destroyed from the actual body weights.

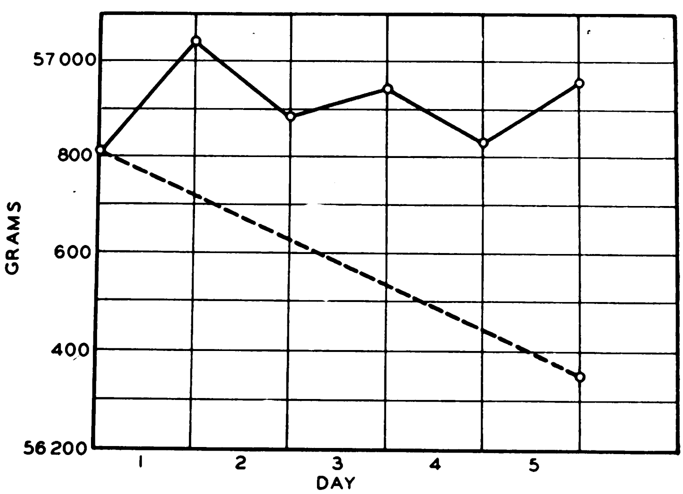
Table VI—ENERGY METABOLISM IN OBESE PATIENTS

RETENTION OF WATER CONCEALS DESTRUCTION OF TISSUE

Date 1929	*Change in Weight of Subject Grams*	*Weight of Body Tissue Destroyed Grams*	[illegible] *Water Balance*
Feb. 3	+285	90	+369
Feb. 4	—225	90	—105
Feb. 5	+65	90	+149
Feb. 6	—125	90	—41
Feb. 7	+115	90	+198
Totals	+115	450	+570

PARADOXICAL GAIN OF WEIGHT BY NORMAL SUBJECT

		PRO.	FAT	CHO	CAL
	METABOLIZED:	69	86	148	1688
	DIET:	63	26	148	1078
BODY LOSSES	SOLIDS:	6	60		
	PREFORMED WATER:	18	6		
	TOTAL:	24 +	66 =	90 GRAMS DAILY	



5 DAYS
ACTUAL GAIN = 115 GRAMS
TISSUE LOSS = 450 GRAMS

Fig. 3.

A normal man gains 115 grams in 5 days in spite of a daily deficit of 610 calories. The accompanying destruction of body tissue amounted to 450 grams. An addition of 565 (115 plus 450) grams of water to the body would permit the recorded gain in body weight. The calculations summarized in Table V indicate that 570 grams of excessive water had been retained by the body.

tissue being destroyed; and that in the second phase, the excessive water was excreted. Table V shows the various items that need to be taken into account in order to know whether water is being added to or lost from the organism. It should be noted that "preformed water" is that water which is an integral part of living tissue and which accordingly becomes an additional source of "free" water when tissue is destroyed. "Insensible water" is calculated from the insensible loss of weight as explained previously. The use of these methods in the study of obese patients showed that whenever weight was lost less rapidly, while they are being underfed, than predicted from the known weight of the destroyed tissue, the difference could be attributed to retention of water. Figure 2 is an example of this condition. The patient weighed the same on the sixteenth day as she did on the first one even though the daily caloric deficit amounted to 1225 calories. During the next nine days, the loss of weight was so rapid that for the whole twenty-four days, the total loss of weight closely approximated the expected loss calculated from the destruction of body tissue. The position of the circles in the diagram was obtained by subtracting the weight of the excessive body water from the actual weight. They show that the difference between the actual weight and what it would have been due to oxidation of body tissue if nothing else had intervened, is accounted for by water retention.

It is of further interest to realize that this accumulation of excessive water is not peculiar to obesity since the phenomenon occurs in normal persons who are receiving low calory diets. Figure 3 shows that a man of normal weight actually gained 115 grams in five days even though his diet contained 610 calories less than he produced per twenty-four hours. Table VI is the water exchange during this period. Since 450 grams of body tissue had been oxidized, it would have required the addition of 565 grams of water to the body to account for a gain of 115 grams of weight. The calculations gave an addition of 570 grams of water.

These periods of water retention may last for a few or many days and may recur frequently or occasionally. In any case they are always followed by periods of accelerated water loss that rid the organism of the excessive water. In time intervals of one or several months the patients will have lost the amount of weight corresponding to the destruction of body tissue.

Conclusions: The energy metabolism of obese patients is normal per square meter of body surface. The total twenty-four hourly heat production of obese persons is greater than normal in proportion to the increased surface area. Obesity is produced by prolonged inflow of energy that is greater than the outflow. To merely maintain an established body weight, obese persons must ingest more energy than comparable persons of normal weight.

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